Entropy-controlled Phase Change Memory with an Extraordinary Small Switching Energy

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Phase-change memory (PCM) is one of the attractive candidates for the future non-volatile memory. The switching mechanism depends on the first phase-transition between amorphous and crystalline states in Ge-Sb-Te alloy through the melting process beyond 930K. Due to the inevitable thermodynamic all process, PCM required for a higher energy in switching than magnetic non-volatile memory (MRAM), while PCM has been keeping the advantage over resistance memory (ReRAM), which requires a higher energy to oxidize a metal or to redox of the metal oxide than PCM. In order to improve the switching energy in PCM in comparison with MRAM, we have developed interfacial phase-change memory (iPCM), which greatly reduces the energy more than 90% using the entropy control [1, 2].

IPCM is a multilayer, which is alternatively formed by a GeTe and a Sb_2Te_3 building block sub-layer sharing a same crystalline growth direction: <111> in GeTe and <0001> in Sb_2Te_3 layers: $[(GeTe)_2(Sb_2Te_3)_x]_y$, where x and y are integers [2]. Each building block is thought to be weakly bonded by van der Waals force in Te - Te atoms. In iPCM model, Sb_2Te_3 blocks do not take part in switching, while in GeTe blocks Ge atoms transits penetrating through a Te atomic sheet with an activation energy of around 2.3 eV [3] when an external electrical field is applied because Ge atoms in GeTe blocks are positively charged slightly. The one dimensional coherent switching by the electrical field enables to reduce the switching entropy drastically in comparison with that through a melting process in then present PCM using a Ge-Sb-Te alloy. Therefore, iPCM has been believed to becomes the successor of the present PCM.

Soon after the first experimental demonstration using the iPCM structure, however, it was discovered that iPCM has a giant magneto-resistivity more than 2000% at room temperature without doping any magnetic element [4]. The property is highly unusual because Ge-Sb-Te alloys are usually non-magnetic unless a magnetic element is doped. In addition, even adding a magnetic dopant such magnetic effect only appears at a very low temperature. The magnetic property was also easily observed and confirmed using a polarized laser under a magnet at room temperature. However, iPCM films are all non-magnetic by SQUID measurement at both low temperature and room temperature. What is different between SQUID and the other measurements: magneto-resistance and Kerr rotation using a polarized laser beam?The physics inducing such magnetic properties has recently been understood.

Sb_2Te_3 is recently known as a three-dimensional (3D) topological insulator, which was experimentally confirmed by angular-resolved photo electron spectroscopy (ARPES), and it has a single Dirac cone at Γ point, which means to be a nontrivial topological insulator [5]. On the other hand, GeTe is a narrow gap semiconductor. As iPCM is composed of Sb_2Te_3 and GeTe building blocks, topologically two different insulators are weakly connected by van der Waals force through each interface between the blocks. From our *ab-initio* computer simulation including spin-orbit coupling effect, it was revealed that an iPCM model (*Reset*) with a spatial inversion symmetry has a Dirac cone at Γ point in the bulk band structure, while another model (*Set*) without the symmetry has a band gap but with non-degenerated bands in spin. In addition, when an external electrical field is applied to the *Reset* model the Dirac cone is splitted, resulting in Rashba effect. In the presentation, we present the experimental evidences of the magnetic properties and the computer simulation results based on topological insulating theory.

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